

# **Measurement of Non-Linear Waves and their Interaction with Surface Waves using Coherent Real Aperture Radars**

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## **LONG-TERM GOALS**

The long-term goal of this project is to understand microwave surface signatures of internal waves in the ocean so that internal waves can be remotely detected and better prediction.

## **SCIENTIFIC OBJECTIVES**

The scientific objectives of this research are 1) to understand the transition from the linear perturbations of surface waves by internal waves studied in the past to the non-linear perturbations embodied by wave breaking, 2) to determine the conditions that make microwave surface signatures of internal waves visible, and 3) to understand better the generation, propagation, and dissipation of internal waves on the ocean

## **APPROACH**

Our approach is to mount Doppler radars on airplanes and ships to image surface effects of internal waves. We do this while other investigators collect surface and subsurface data to determine environmental conditions and the characteristics of the internal waves. By analyzing these data sets together, we determine how properties of internal waves, wind, and surface waves affect the observed microwave signatures. In FY05, we mounted a Doppler radar on the R/V Revelle and collected data in the South China Sea. In FY06 we mounted Doppler radars on the R/V Endeavor and on a Cessna Skymaster airplane and made measurements off the New Jersey coast. In FY07, we intend to again collect shipboard data in the South China Sea.

## **WORK COMPLETED**

In March, 2005, we installed our pulsed Doppler radar, RiverRad, on the R/V Revelle with parabolic antennas pointed toward the ship's bow. Measurements were made in the South China Sea as part of SCS05. In August, 2006, we mounted RiverRad on the R/V Endeavor with parabolic antennas that scanned about 78 degrees. Measurements were made off the New Jersey coast as part of SW06. In both cases, one antenna was vertically polarized and the other was horizontally polarized.

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**Figure 1.** *RiverRad mounted on the R/V Revelle in 2005 (left) and on the R/V Endeavor in 2006 (right). The parabolic antennas were fixed in 2005 and scanned in 2006.*

Also in SW06, we mounted our airborne Doppler radar, CORAR, on a Cessna Skymaster leased from Ambroult Aviation of Chatham, MA. Two antennas were mounted under the fuselage, one vertically polarized, the other horizontally polarized. We flew patterns over the ships operating near the internal waves generated at the shelf break on 15 occasions on 11 different days.



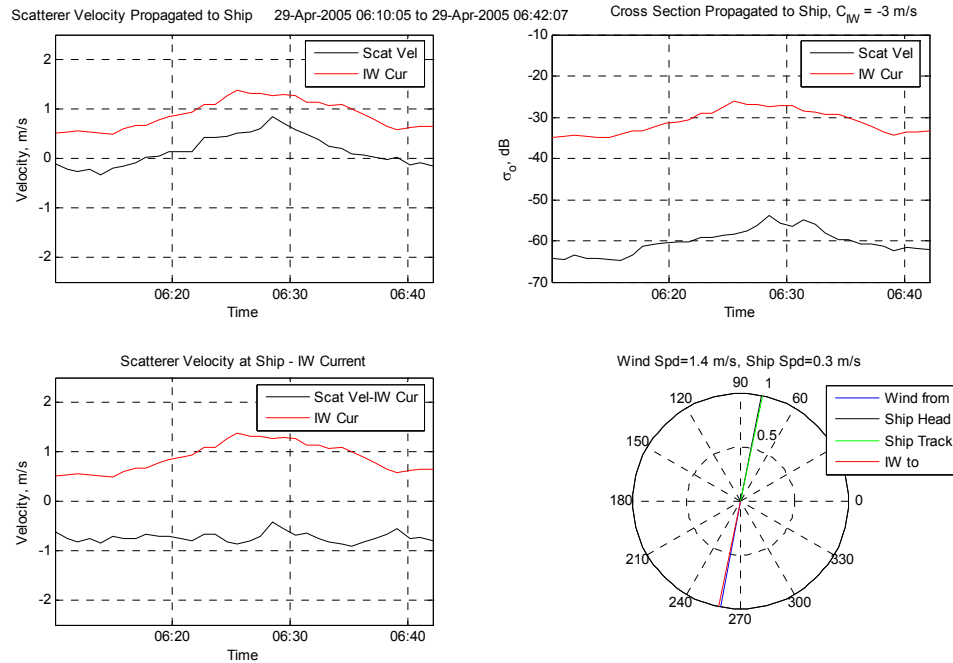
**Figure 2.** *CORAR on the Cessna Skymaster in 2006 during SW06. Left - Electronics rack in the plane. Right – Antennas mounted underneath the plane.*

## RESULTS

### SCS05:

The radar data collected on the R/V Revelle have now been correlated with subsurface velocities measured on the ship using an ADCP. The latter data were provided to us by Jody Klymak and Rob Pinkel. Figure 3 gives an example of the results. These results are at VV polarization; our HH channel failed. The conclusion from this and a variety of similar measurements from RiverRad is that X-band radar cross sections at VV polarization and low incidence angles are modulated by internal waves in phase with their currents, not out of phase with their strain rate as has been found for weaker internal waves and higher grazing angles. Also, the scatterer velocities at X-band, VV polarization, and low grazing angles track the internal wave subsurface velocities well, but have an offset due to the

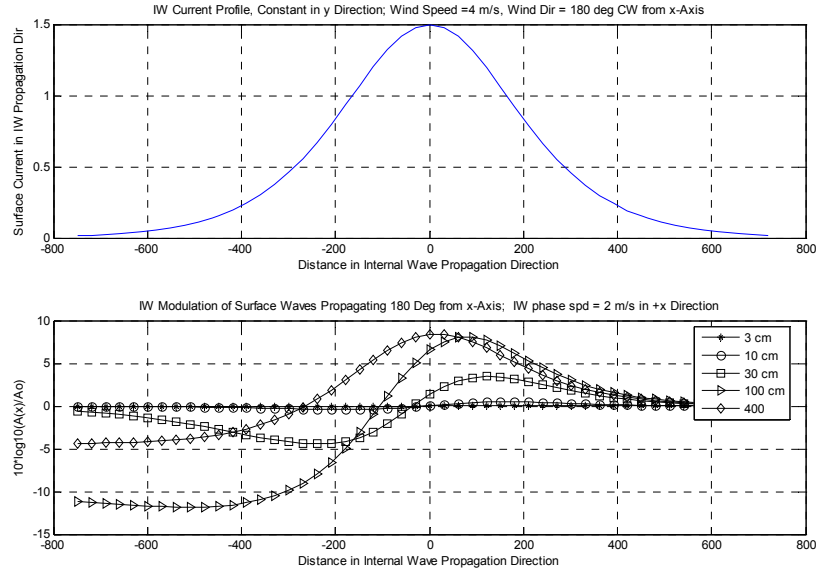
mean scatterer velocity caused by shadowing. This offset was confirmed by extensive measurements of mean scatterer velocity versus wind speed.



**Figure 3. Comparison of RiverRad backscatter measurements from the R/V Revelle with subsurface currents in internal waves measured using a shipboard ADCP. Top left: Radar measured scatterer velocities (black) and subsurface current (red). Top right: Radar cross section (black) and subsurface current (red). Bottom left: difference between scatterer velocity and subsurface current (black). Bottom left: Directions of various quantities.**

Our complete, analyzed data set from SCS05 was distributed to all NLIWI remote sensing investigators. A historical review of internal wave measurements was also compiled and distributed to the NLIWI remote sensing team.

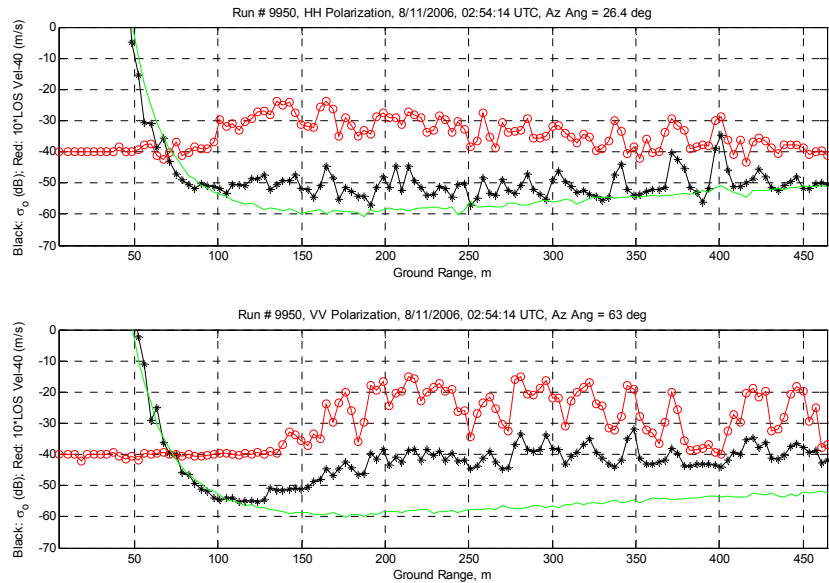
In an effort to understand why our results appear different from previous studies at moderate incidence angles, modeling was begun in collaboration with Ellen Lettvin and Brad Bell, both of APL/UW. A subroutine was developed to solve the action balance equation for various wind speeds, internal wave currents, and short waves. Figure 4 shows preliminary modeling results for surface waves propagating opposite to the internal wave propagation direction and a wind speed of 4 m/s. These results are in agreement with those of Thompson (JGR, vol 93, 1988) and imply that X-band modulation cannot be explained as a direct modulation of 3 cm waves by internal wave currents. As suggested by Thompson and Lyzenga (JGR, vol. 103, 1998) X-band modulation probably includes modulation by intermediate scale waves that are themselves modulated by the internal wave currents. Our results indicate that these intermediate waves have wavelengths of about 4 meters. Our modeling work is continuing with the goals of looking at various short wave travel directions, the effects of intermediate waves, and comparisons of model and data.



**Figure 4. Modulation of surface waves of the wavelengths indicated in the lower plot by internal wave currents given in the upper plot. The results were obtained by solving the action balance equation numerically.**

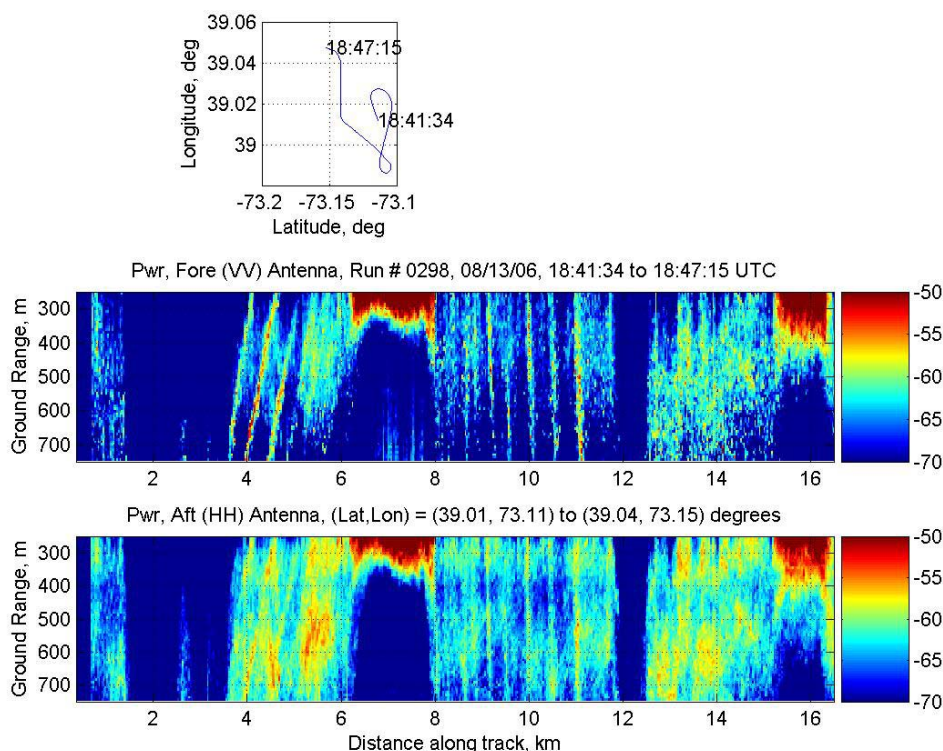
SW06:

Neither the shipboard nor the airborne data from SW06 have been analyzed yet. Preliminary indications of the data quality are shown in Figures 5 and 6.



**Figure 5. Cross sections (black) and scatterer velocities (red) from RiverRad on the R/V Endeavor during SW06. The green line indicates the system noise level. Note the high correlation between cross section and scatterer velocity.**

Figure 5 shows cross sections and scatterer velocities derived from the two antennas of RiverRad on the R/V Endeavor. This data set primarily shows effects of surface waves but the correlation between scatterer velocity and cross section is obvious in both HH and VV polarized data. This correlation turns negative when looking downwind as it should. Figure 6 shows images of power received from internal waves at HH and VV polarization from CORAR on the Skymaster. Flights were in several different directions. Work is underway to produce images of cross sections and scatterer velocities.



**Figure 6.** *Internal wave patterns in the cross sections measured by CORAR on the Cessna Skymaster at HH and VV polarizations and different flight directions. The track of the aircraft is shown in the upper panel.*

## IMPACT/APPLICATION

These measurements and modeling will help establish the relationship between remotely observed microwave signatures of internal waves on the sea surface and the properties of the internal waves. This will aid in the prediction of internal wave location and intensity for use in submarine navigation and acoustic propagation calculations in the internal wave field.

## TRANSITIONS

The results of this project have not yet been transitioned for operational use.

## RELATED PROJECTS

This project is part of the NLIWI experiment and is strongly related to the WISE/VANS experiment and to the Surface Wave 06 acoustic experiment.